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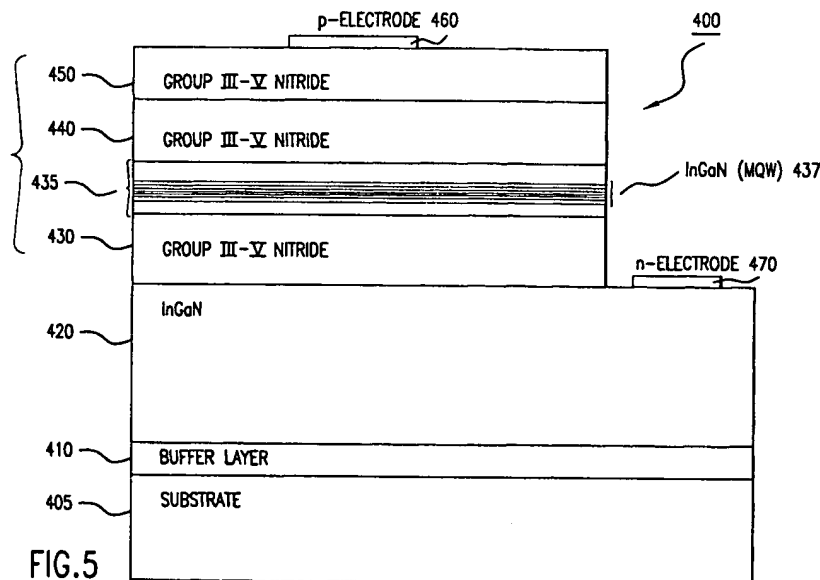
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**(54) AlGaInN LED and laser diode structures**

(57) Group III-V nitride semiconductors are used as optoelectronic light emitters. The semiconductor alloy InGaN is used as the active region in nitride laser diodes and LEDs, as its bandgap energy can be tuned by adjusting the alloy composition, to span the entire visible spectrum. InGaN layers of high-indium content, as required for blue or green emission are difficult to grow, however, because the poor lattice mismatch between GaN and InGaN causes alloy segregation. In this situation, the inhomogeneous alloy composition results in spectrally impure emission, and diminished optical gain. To suppress segregation, the high-indium-content In-

GaN active region may be deposited over a thick InGaN layer, substituted for the more typical GaN. First depositing a thick InGaN layer establishes a larger lattice parameter than that of GaN. Consequently, a high indium content heterostructure active region grown over the thick InGaN layer experiences significantly less lattice mismatch compared to GaN. Therefore, it is less likely to suffer structural degradation due to alloy segregation. Thus, the thick GaN structure enables the growth of a high indium content active region with improved structural and optoelectronic properties, leading to LEDs with spectrally pure emission, and lower threshold laser diodes.



## Description

**[0001]** The invention relates to the field of semiconductors. More particularly, the invention is directed to group III-V nitride semiconductor films usable in blue light emitting devices.

**[0002]** The light-emitting diode is the basic component for electronic lighting technology. A light-emitting diode is a relatively simple semiconductor device which emits light when an electric current passes through a p-n junction of the light-emitting diode. As shown in Figure 1, a light-emitting diode 100 includes a p-type 110 semiconductor material adjacent to an n-type 120 semiconductor material, i.e., a p-n junction, characterized by a bandgap energy  $E_g$  130. The bandgap energy 130 is the minimum energy required to excite an electron 160 from a valence band 140 to a conduction band 150, where the electron 160 becomes mobile. Likewise, the bandgap energy 130 also determines the energy of a photon produced when the electron 160 in the conduction band, i.e., a conduction electron, recombines with a hole 170, i.e., an unoccupied electronic state, in the valence band 140. When forward current passes through the diode 100, the electrons 160 in the conduction band 150 flow across the junction from the n-type material 120, while the holes 170 from the valence band 140 flow from the p-type material 120. As a result, a significant number of the electrons 160 and the holes 170 recombine in the p-n junction, emitting light with an energy  $E_{\text{photon}} = E_g$ . These semiconductor devices, comprising a p-n junction, in a single material, and are referred to as homo-junction diodes.

**[0003]** In order to obtain more efficient LEDs and laser diodes, in particular, lasers that operate at room temperature, it is necessary to use multiple layers in the semiconductor structure. These devices are called heterojunction or heterostructure LEDs or lasers.

**[0004]** The wavelength, and thus the color of light emitted by an LED or laser diode, depends on the bandgap energy  $E_g$ . LEDs or laser diodes that emit light in the red-to-yellow spectrum have been available since the 1970's. There has been great difficulty, however, in developing efficient LEDs that emit light at shorter wavelengths. Extending LED light sources into the short-wavelength region of the spectrum, the region extending from green to violet, is desirable because LEDs can then be used to produce light in all three primary colors, i.e., red, green, and blue. Shorter-wavelength laser diodes will likewise enable full-color projection displays; and they will also permit the projection of coherent radiation to focus laser light into smaller spots. That is, in the optical diffraction limit, the size of the focused spot is proportional to the wavelength of the light. Reducing the wavelength of the emitted light allows optical information to be stored at higher densities and read out more rapidly.

**[0005]** Fig. 2 shows a conventional LED structure 200 in which an InGaN active layer 230 is formed over a

group III-V nitride layer 220. Specifically, as shown in Fig. 2, the conventional LED 200 includes a substrate 205, which may, for example, be formed of sapphire or silicon carbide. A buffer layer 210 is formed on the substrate 205. The group III-V nitride layer 220 is then formed on the buffer layer 210. The group III-V nitride layer 220 is typically GaN. The InGaN active layer 230 is formed on the group III-V nitride layer 220. A second group III-V nitride layer 240 is then formed on the InGaN active layer 230. A third group III-V nitride layer 250 is formed on the second group III-V layer 240. The first group III-V nitride layer 220 is n-type doped. The second and third group III-V nitride layers 240 and 250 are p-type doped. A p-electrode 260 is formed on the third group III-V nitride layer 250. An n-electrode 270 is formed on the first group III-V nitride layer 220.

**[0006]** This invention provides group III-V nitride films formed on substrates usable to form short-wavelength visible light-emitting optoelectronic devices, including light-emitting diodes (LEDs) and diode lasers.

**[0007]** This invention provides a method for growing light-emitting device heterostructures over a thick InGaN layer that provides a suitable bandgap for blue, green, or even red light emission.

**[0008]** The invention provides a stable InGaN structure that avoids lattice mismatch.

**[0009]** The invention provides other electronic devices, such as transistors, which can incorporate InGaN with other group III-V semiconductors.

**[0010]** Group III-V nitrides include elements from groups III, i.e., gallium, indium, and aluminum, and V, i.e., nitrogen, of the periodic table. These materials are deposited over substrates forming layered structures for optoelectronic devices, including LEDs and laser diodes. The resulting devices can emit visible light over a wide range of wavelengths.

**[0011]** The performance of the optoelectronic devices depends on the quality of the group III-V nitride films formed over the substrates. An important structural characteristic of the group III-V nitride films, which affects their emission quality, is lattice matching between each of the layers. In particular, lattice mismatch occurring between dissimilar materials may produce crystal defects, such as dislocations, cracks, or alloy inhomogeneity, which degrade the optoelectronic quality of the material.

**[0012]** The group III-V nitride semiconductors, GaN, AlN and InN, are used in visible light emitters because these materials are characterized by a wide bandgap energy, as is necessary for short-wavelength visible light emission. Group III-V nitrides also form strong chemical bonds, which make the material very stable and resistant to degradation under high electrical current densities and intense light illumination.

**[0013]** Most optoelectronic devices based on the group III-V nitride compounds require growth of a sequence of layers with different bandgap energies and refractive indices. The bandgap energy of the active lay-

er determines the wavelength of light emitted from a light-emitting diode or laser. In addition, the energy band and refractive index discontinuities between layers of different composition provides for optical and carrier confinement. To obtain layers with the bandgap around 2.7 eV, which will produce light in the blue region of the spectrum, InGaN alloys can be used. The bandgap energy of GaN is 3.4 eV, while the bandgap energy of InN is 1.9 eV. Therefore,  $\text{In}_x\text{Ga}_{1-x}\text{N}$  alloys span the visible spectrum, in which case an estimated In composition  $x$  of about 30%, i.e.,  $\text{In}_{0.3}\text{Ga}_{0.7}\text{N}$ , is required to obtain blue-light emission, 50% for green emission, and 100%, i.e., InN, for red emission.

**[0014]** Growing InGaN alloys with such a high In content on GaN has heretofore been, if not impossible, difficult using conventional techniques, such as metal-organic chemical vapor deposition (MOCVD). Specifically, when using these conventional techniques, the InGaN alloy active region tends to segregate. As the indium content is increased to produce longer-wavelength emission, the InGaN alloy becomes unstable. As a result of this instability, the InGaN alloy separates, or segregates, into In-rich regions and Ga-rich regions, so that the InGaN alloy composition, and therefore the active region bandgap energy, is no longer uniform.

**[0015]** This inhomogeneous composition causes the electroluminescence (EL) to be spectrally broad, i.e., where a broad range of wavelengths is emitted. For instance, while the spectral emission widths of violet LEDs (390 - 420 nm.), corresponding to 10-20% In content, may be as narrow as 10-15 nm, the spectral emission width increases to 20-30 nm for blue LEDs (430-470 nm.), corresponding to a ~30% In content, and 40-50 nm for green LEDs (500-530 nm.), corresponding to a ~50% In content.

**[0016]** The poor spectral purity of green LEDs limits their application in full-color displays, where pure colors are needed to generate, by additive mixing, a broader palette of colors. Likewise, such broad spectral emission widths also translate into a broad gain spectrum for laser diode structures. When the gain spectrum becomes broad, the peak gain is reduced, so that it becomes difficult to reach the laser oscillation threshold. For this reason, when formed using these conventional techniques, the performance of blue and green group III-V nitride laser diodes is poor compared to violet-emitting group III-V laser diode devices. Indeed, a true blue nitride laser has not yet been demonstrated; and green nitride laser diodes present even greater difficulty, due to their requisite higher In content.

**[0017]** In order to improve the spectral purity of blue and green LEDs, and to promote the development of true blue or green group III-V nitride laser diodes, the growth of high-indium-content InGaN alloys, with homogeneous alloy content, is necessary. The alloy segregation problems must be overcome, so that the alloy content remains uniform, even when the indium content approaches 50%. Presently, alloy segregation limits the In

content of nitride lasers to values less than 20%, corresponding to violet and near-ultraviolet emission. While this short wavelength is ideal for optical storage, longer wavelengths, i.e., blue-green-red, are required for applications such as projection displays and undersea communication.

**[0018]** Because the bandgap of GaN is 3.4 eV and the bandgap of InN is 1.9 eV, a group III-V alloy with an In composition of about 30% is required in order to obtain the blue light emission in the conventional LED structure 200 described above. However, GaN and InN have a very large lattice mismatch, which may induce phase separation of InGaN alloys of high In content. Thus, it has heretofore been very difficult to form an InGaN alloy having an In content higher than 20%, where excellent optoelectronic quality is preserved, using conventional growth techniques. Thus, constructing effective pure blue, green, or red light emitting structures using InGaN grown over group III-V nitride layers has proven very difficult

**[0019]** The inventors have determined that these problems may be caused by the lattice mismatch of over 10% between GaN and InN, which can cause alloy segregation. Thus,  $\text{In}_x\text{Ga}_{1-x}\text{N}$  alloys with homogeneous alloy content  $x$  higher than 20% have been difficult to achieve using the conventional techniques, such as MOCVD.

**[0020]** Thus, it would be advantageous to integrate InGaN with other group III-V nitrides, in a manner which avoids the problems of the conventional structures described above.

**[0021]** This invention thus provides a novel semiconductor structure that incorporates a thick InGaN layer. In the modified layer structure according to the invention, a thick InGaN layer replaces the thick GaN layer, which is normally incorporated into the device structure, as both a dislocation filter and a lateral n-contact layer. Depositing a thick InGaN layer establishes a larger lattice parameter compared to the typical GaN template which is employed for overgrowth of the device heterostructure. Consequently, a high-indium-content heterostructure active region grown over the thick InGaN layer experiences less mismatch strain compared to the high-indium-content heterostructure conventionally grown over GaN. Therefore, the device is less likely to suffer structural degradation due to alloy segregation. In this manner, a thick InGaN structure enables the growth of high-indium-content active regions with improved structural and optoelectronic properties. By overcoming the obstacles associated with the InGaN alloy segregation, the compositional uniformity of InGaN layers is improved, so that the spectral emission of blue, green, and even red LEDs becomes more pure. Similarly, the gain spectra of visible nitride laser diodes is also sharper, so that the peak gain is greater, for low threshold. A further benefit of the thick InGaN layer is its superior function as a lateral contact layer. This is a consequence of InGaN's lower bandgap energy, which

contributes to a lower contact resistance, and to higher electron mobility and concentration.

**[0022]** These and other features and advantages of invention are described in or are apparent from the following detailed description of the preferred embodiments.

#### BRIEF DESCRIPTION OF THE DRAWINGS

**[0023]** The preferred embodiments of the invention will be described in detail, with reference to the following figures in which:

Fig. 1 shows a conventional p-n junction device;  
 Fig. 2 shows the structure of a conventional LED;  
 Fig. 3 shows the structure of an LED according to an embodiment of the invention;  
 Fig. 4 shows the LED structure of Fig. 3 according to another embodiment of the invention;  
 Fig. 5 shows the structure of a diode laser according to another embodiment of the invention; and  
 Fig. 6 shows the laser diode structure according to an embodiment of the invention incorporated into a reprographic printing system.

**[0024]** Fig. 3 shows a multi-layer LED structure 300 according to an embodiment of this invention. Specifically, Fig. 3 shows an LED heterostructure grown over a thick InGa<sub>N</sub> layer, which permits the realization of an unsegregated, high-indium-content InGa<sub>N</sub> alloy active region for brighter, and more spectrally pure, emission of light. As shown in Fig. 3, the LED 300 includes a single-crystal substrate 305, which may be formed by any known or later developed substrate material, such as, for example, sapphire, silicon carbide or spinel. In the case of sapphire, A and C-oriented single crystal sapphire is preferable for optoelectronic devices. The substrate 305 is typically several hundred microns thick, i. e., 100-500  $\mu\text{m}$  thick.

**[0025]** A buffer layer 310, also known as a nucleation layer, is formed over the substrate 305. The buffer layer 310 serves primarily as a wetting layer, to promote smooth, uniform coverage of the sapphire substrate. The buffer layer 310 is typically formed of either Ga<sub>N</sub>, InGa<sub>N</sub>, Al<sub>N</sub> or AlGa<sub>N</sub>. The buffer layer 310 typically has a thickness of about 100-500 Å. The buffer layer 310 should have a lattice orientation that is substantially aligned to that of the substrate. The buffer layer 310 is typically deposited as a thin amorphous layer. The buffer layer 310 is typically deposited at a low temperature, then crystallized through a solid-phase epitaxy process, usually coincident with the temperature being raised for the remainder of the structure. However, any known or later developed method for forming the described buffer layer 310 can be used.

**[0026]** The buffer layer 310 may also be formed as a plurality of layers. For example, Fig. 4 shows the LED structure 300 of Fig. 3 with a second buffer layer 312.

The two buffer layers 310 and 312 can have different alloy concentrations or be deposited under different conditions to promote smooth film growth and to accommodate the large lattice mismatch. The remaining layers 305, 320, 330 and 340 are identical to the layers formed in Fig. 3.

**[0027]** A thick InGa<sub>N</sub> layer 320 is then deposited over the buffer layer 310. The thick InGa<sub>N</sub> layer 320 is n-type doped and is typically grown to a thickness between 0.5  $\mu\text{m}$  and 100  $\mu\text{m}$ . An InGa<sub>N</sub> active layer 330 is then deposited over the thick InGa<sub>N</sub> layer 320. The InGa<sub>N</sub> active layer 330 can be used to form blue, green, and even yellow or red LEDs. The InGa<sub>N</sub> active layer 330 is typically about 10-100 Å thick.

**[0028]** While relatively unsegregated InGa<sub>N</sub> films with an indium content of up to about 20% can be grown over thick Ga<sub>N</sub>, the indium content is extendible to, for example, 50% by growing the InGa<sub>N</sub> film over a thick InGa<sub>N</sub> layer of approximately 30% indium, because this represents a similar magnitude of lattice mismatch. The InGa<sub>N</sub> active layer 330 is thus a high indium content heterostructure active region which experiences less lattice mismatch strain than compared to an InGa<sub>N</sub> film grown directly over Ga<sub>N</sub>. By reducing the lattice mismatch, InGa<sub>N</sub> alloy phase separation is minimized, thus preserving the optoelectronic quality of the active region material, which is most critical.

**[0029]** A first group III-V nitride layer 340 is then formed over the InGa<sub>N</sub> active layer 330. A second group III-V nitride layer 350 is formed over the first group III-V nitride layer 340. The first group III-V nitride layer 340 and the second group III-V nitride layer 350 are p-type doped. Typical group III-V nitrides used for these layers include Ga<sub>N</sub>, InGa<sub>N</sub>, AlGa<sub>N</sub> or AlInGa<sub>N</sub>; and the first group III-V nitride layer 340 typically has a higher bandgap energy than the second group III-V nitride layer 350, so as to better confine injected electrons to the active region. A p-electrode 360 is formed over the second group III-V nitride layer 350. The second group III-V nitride layer 350 serves as a contact layer, and so is preferably highly p-type doped, and of lower bandgap energy, corresponding to a lower Schottky barrier at its interface with the metal electrode 360. An n-electrode 370 is formed over the thick InGa<sub>N</sub> layer 320. All of the layers 310, 320, 330, 340 and 350 described above may be formed by any conventional or later developed technique, such as, for example, molecular beam epitaxy, hydride vapor phase epitaxy or MOCVD.

**[0030]** As is known in the art, multiple confinement and contact layers can be provided within the LED structure 300. The first and second group III-V nitride layers 340 and 350 are illustrative and are not meant to limit the number of group III-V layers which may be formed within the LED structure.

**[0031]** In operation, a positive (forward) bias is applied between the p-electrode 360 and the n-electrode 370. Electrons in the conduction band flow from the n-doped thick InGa<sub>N</sub> layer 320 to a lower energy state in

the InGaN active layer 330. Current applied at the p-electrode 360 causes holes in the valance band of the first and second group III-V nitride layers 350 and 340 to flow into the InGaN active layer 330. Thus, electrons from the n-doped InGaN layer 320 combine with holes from the p-doped group III-V nitride layers 340 and 350 in the InGaN active layer 330. Recombination of holes and electrons in the active layer 330 results in the emission of light, with photon energy equal to the InGaN active region's bandgap energy. In this case, when the active region has a bandgap of about 2.7 eV, light in the blue region of the spectrum is emitted. An active region of higher indium content would produce longer wavelength (green-red) emission. The thick InGaN layer 320 and the group III-V nitride layers 340 and 350 act as confinement layers, shepherding the electrons and holes into the lower energy InGaN active layer 330, maximizing the number of electrons and holes which recombine in the active region 330. Light is emitted in all directions.

**[0032]** Fig. 5 shows a laser diode structure 400 according to another embodiment of the invention. In this embodiment, a thick InGaN layer 420 is formed instead of the conventional GaN layer 220 shown in Fig. 2. This, establishes a template of larger lattice parameter, for overgrowth of the laser heterostructure; and thereby permits the realization of a compositionally homogeneous, high-indium-content InGaN alloy active region, thus producing bright and spectrally pure light emission. The entire laser diode heterostructure 480 is grown over the thick InGaN layer 420.

**[0033]** The laser diode 400 includes a substrate 405, which may be formed by any known or later developed substrate material, such as, for example, sapphire, silicon carbide or spinel. The substrate is typically about 100 to 500  $\mu\text{m}$  thick.

**[0034]** A buffer layer 410 is formed over the substrate 400. The buffer layer 410 serves primarily as a wetting layer and promotes smooth and uniform coverage of the sapphire substrate 405. The buffer layer 410, also known as a nucleation layer, is typically formed of either GaN, InGaN, AlN or AlGaIn. The buffer layer 410 has, typically, a thickness of about 100 to 500 Å thick. The buffer layer 410 should have a lattice orientation that is substantially aligned to that of the sapphire substrate 405. The buffer layer 410 is typically deposited as a thin amorphous layer. The buffer layer 410 is typically deposited at a low temperature, then crystallized through a solid phase epitaxy process. However, any known or later developed method for forming the deposited buffer layer 410 can be used.

**[0035]** The buffer layer 410 may also be formed as a plurality of layers. For example, multiple buffer layers may be incrementally formed over the substrate 400. The two or more buffer layers can have different alloy concentrations or be deposited under different conditions to promote smooth film growth and to accommodate the large lattice mismatch

**[0036]** A thick InGaN layer 420 is then formed over the buffer layer 410. The thick InGaN layer 420 is n-type doped and is typically about 0.5  $\mu\text{m}$  to 100  $\mu\text{m}$  thick. After the thick InGaN layer 420 is formed, the device heterostructure is formed. In forming the device heterostructure according to this invention, an n-type cladding layer is first formed. The n-cladding layer is a first group III-V nitride layer 430 formed over the thick InGaN layer 420. The first group III-V nitride layer 430 is n-type doped and is about 0.2 to 2  $\mu\text{m}$  thick. A composite InGaN active layer and waveguide 435 are then formed over the InGaN layer 430. The overall thickness of this composite waveguide is 0.05-0.4  $\mu\text{m}$ . Contained within the waveguide is an InGaN quantum well active region 437, comprised of quantum wells which are typically about 10 to 100 Å thick. The InGaN active region 437 may have a single well structure or a multiple well structure. Thus, the active layer 435 acts as a waveguide and includes with its structure the active region 437. Gain, which results in the emission of light, is generated within the active region 437.

**[0037]** A second group III-V nitride layer 440 is formed over the InGaN active layer 435. A third group III-V nitride layer 450 is formed over the second group III-V nitride layer 440. Both the second and third group III-V nitride layers 440 and 450 are p-type doped. The second group-III nitride layer 440 serves as a p-type cladding layer, and is typically about 0.2  $\mu\text{m}$  to 2  $\mu\text{m}$  thick. The third group III-V nitride layer 450 facilitates the formation of a minimum-resistance metal electrode, to contact the p-side of the heterostructure; its thickness is typically 0.01  $\mu\text{m}$  - 2  $\mu\text{m}$ . The first, second and third group III-V nitride layers 430, 440 and 450 each may be formed of GaN, AlGaIn, InGaIn and/or AlInGaIn.

**[0038]** A p-electrode 460 is formed over the third group III-V nitride layer 450 and an n-electrode 470 is formed over the thick InGaN layer 420. The group III-V nitride layers 440 and 430 all serve as layers for optical and electrical confinement. These materials are characterized by a higher bandgap energy and lower refractive index, compared with the thick InGaN active layer 435. All of the layers 410, 420, 430, 435, 437, 440 and 450 described above may be formed by any conventional or later developed technique, such as, for example, molecular beam epitaxy, hydride vapor phase epitaxy or MOCVD.

**[0039]** Multiple confinement and contact layers can be provided within the laser diode structure 400. Thus, the first, second and third group III-V nitride layers 430, 440 and 450 are illustrative and are not meant to limit the number of group III-V layers which may be formed within the laser diode structure 400.

**[0040]** In operation, a positive (forward) bias is applied between the p-electrode 460 and the n-electrode 470. Electrons in the conduction band flow from the n-doped layers 420 and 430 to a lower energy state in the InGaN active region 437. Holes in the valance band of the group III-V nitride layers 450 and 440 flow from the

p-doped layers 450 and 440 into the InGaN active layer 437. Recombination of holes and electrons in the active layer 435 causes the emission of light. In the case of a blue laser, the InGaN active layer 435 has a bandgap energy of about 2.7 eV, so that light in the blue region of the spectrum, i.e.,  $\lambda \sim 470$  nm, is emitted. To date, for heterostructures grown over thick GaN layers, such a long wavelength has been impossible to achieve, due to the alloy segregation of the InGaN active region.

**[0041]** The light-emitting diode 300 and laser diode 400 described above are appropriate for long-wavelength operation. Thus, the other layers which comprise this heterostructure may be different from those used for conventional shorter-wavelength structures grown on a thick GaN layer, as described above. For example, in the conventional structure, AlGaIn alloys of 5-20% Al are required in order to confine injected carriers and to create a transverse waveguide. The requirement for Al-GaN layers in the conventional structures creates a serious problem because of cracking and also because of the difficulty associated with p-type doping (where the acceptor activation energy increases with Al content).

**[0042]** In contrast, the longer wavelength, high-indium-content active region structures according to this invention do not require the high bandgap and low index of AlGaIn alloys for optical and carrier confinement. Instead, low-aluminum-content AlGaIn, GaN or even InGaIn offer sufficient confinement. Thus, at longer wavelengths, the entire heterostructure can use lower bandgap alloys than the conventional structure 200 shown in Fig. 2. These lower bandgap alloys are also beneficial with respect to ease of p-doping, and ohmic contact formation.

**[0043]** There is substantial experimental evidence that the approach described above of reducing the lattice mismatch can improve the quality of high-indium-content InGaIn. For example, "The Composition Pulling Effect of MOVPE Grown InGaIn on GaN and AlGaIn and its TEM Characterization," by K. Hiramatsu et al. MRS Internet Journal of Nitride Research 2, article 6 (1997) (Hiramatsu), suggests that structural qualities of InGaIn layers are strongly dependent upon the surface the InGaIn layers that it was epitaxially deposited onto. For instance, Hiramatsu discloses that when InGaIn was grown on thick GaN or AlGaIn layers, the InGaIn structural quality strongly deteriorated as the layer became thicker or was grown with higher-indium content. In particular, the alloy underwent phase segregation in cases of large lattice strain. This explains the absence of blue and green laser diodes and the poor spectral purity of green LEDs.

**[0044]** More importantly, Hiramatsu suggests that InGaIn grown directly on a very thin GaN, AlN or AlGaIn buffer (nucleation) layer exhibited superior structural and optoelectronic properties. This suggests that the InGaIn segregation is a result of lattice mismatch, and is not a result of a miscibility gap associated with the InGaIn alloy. Thus, by establishing an epitaxial template

of larger lattice parameter, which is better matched to high-indium-content InGaIn alloys, phase segregation can be avoided. Consequently, it is possible to grow high-quality, high-indium content InGaIn layers on InGaIn rather than GaN, to form active regions of blue, green (and even yellow or red) LEDs and laser diodes. While InGaIn films with an indium content up to about 20% could previously be grown on thick GaN, according to this invention, the indium content of the InGaIn films is now extendible, for example to 50%, by growing such an InGaIn film over an InGaIn layer of about 30% indium, because this represents a similar magnitude of lattice mismatch.

**[0045]** The laser diode structure according to the invention described above can be applied to any device requiring compact laser structures, including high resolution laser printing devices, digital printers, display devices, projection displays, high density optical storage devices, including magneto-optical storage devices, including CD-ROM and DVD's whereby data is stored on a magneto-optical disk, fiber-optic communications devices, including for fiber optic emitters and repeaters and undersea communications devices (sea water is most transparent in the blue-green spectrum). The LED structure according to the invention can also be applied to any device requiring compact LED structures, including illumination devices and full color displays, including monolithically integrated pixels for full color displays.

**[0046]** Fig. 6 shows the laser diode structures according to an embodiment of the invention implemented into a laser printing device. Fig. 6 shows a printer 610 which includes a raster output scanner (ROS) 620, a paper supply 630, a print module 640 and finisher 650. A laser diode structure 660 is incorporated into the ROS 620 for providing efficient scanning optics.

## Claims

1. A semiconductor structure, comprising:

a nucleation layer;  
a thick InGaIn layer grown over the nucleation layer; and  
an active layer formed over the thick InGaIn layer.

2. The semiconductor structure according to claim 1, further comprising at least one group III-V nitride layer formed over the active layer, wherein the thick InGaIn layer and the at least one group III-V nitride layer form confinement layers, confining injected carriers to the active layer.

3. The semiconductor structure according to claims 1-2, wherein the active layer includes a waveguiding layer and a quantum well active region.

4. The semiconductor structure according to claims 1-3, wherein the active layer comprises InGaN.
5. The semiconductor structure according to claims 1-4, wherein the semiconductor structure is an optoelectronic device. 5
6. The semiconductor structure according to claims 1-5, wherein the semiconductor structure emits light with a wavelength within a range including 430 nm to 650 nm. 10
7. An image forming apparatus that forms an image on a light sensitive medium, the image forming apparatus including at least one light source that includes the semiconductor structure according to claims 1-6. 15
8. A data storage apparatus that stores data on a medium, the data storage apparatus including at least one light source that includes the semiconductor structure according to claims 1-6. 20
9. A communications apparatus that communicates information through a communications transmission medium, the communications apparatus including at least one light source that includes the semiconductor structure according to claims 1-6. 25
10. A method of forming a semiconductor structure, comprising the steps of: 30
  - forming a nucleation layer;
  - forming a thick InGaN layer over the nucleation layer; and 35
  - forming an active layer over the thick InGaN layer.

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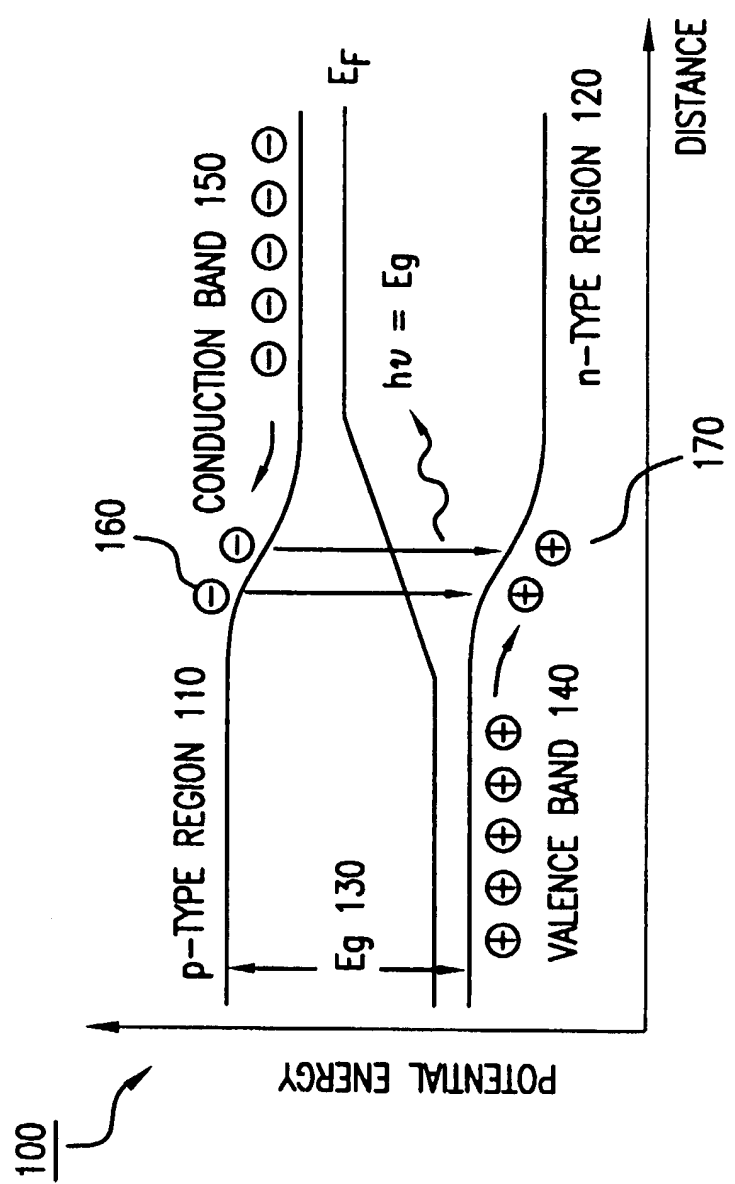


FIG.1



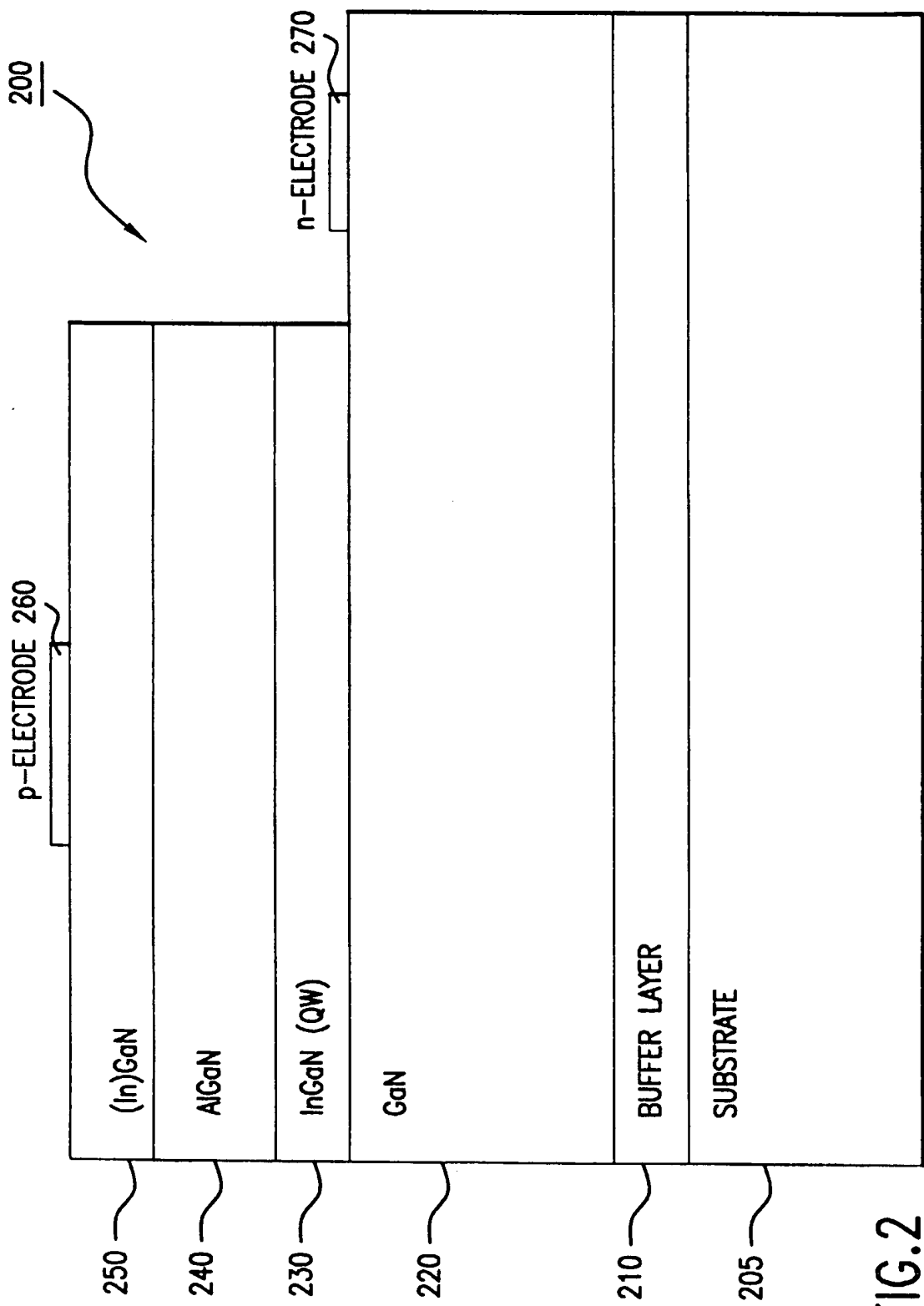


FIG.2

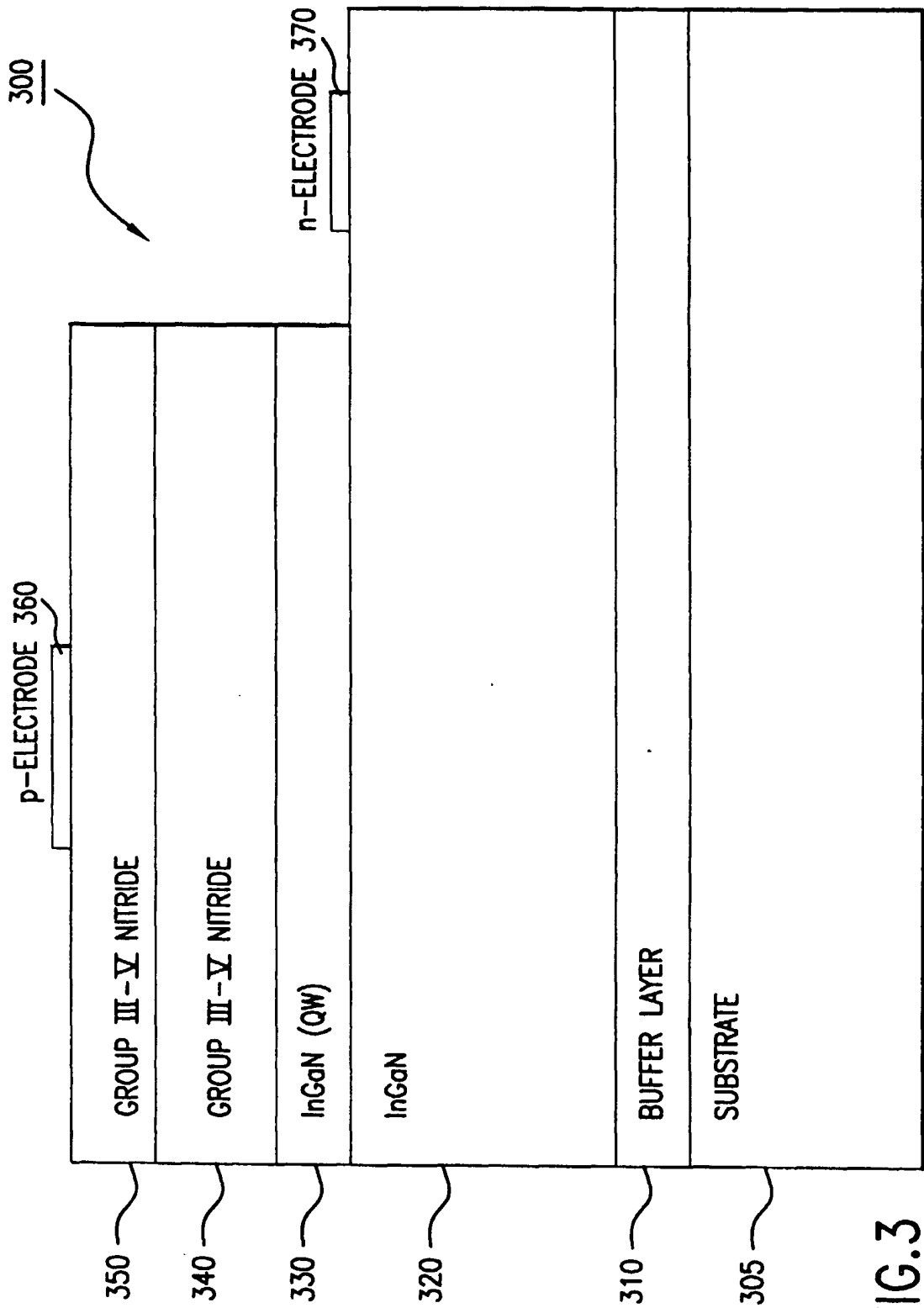


FIG.3

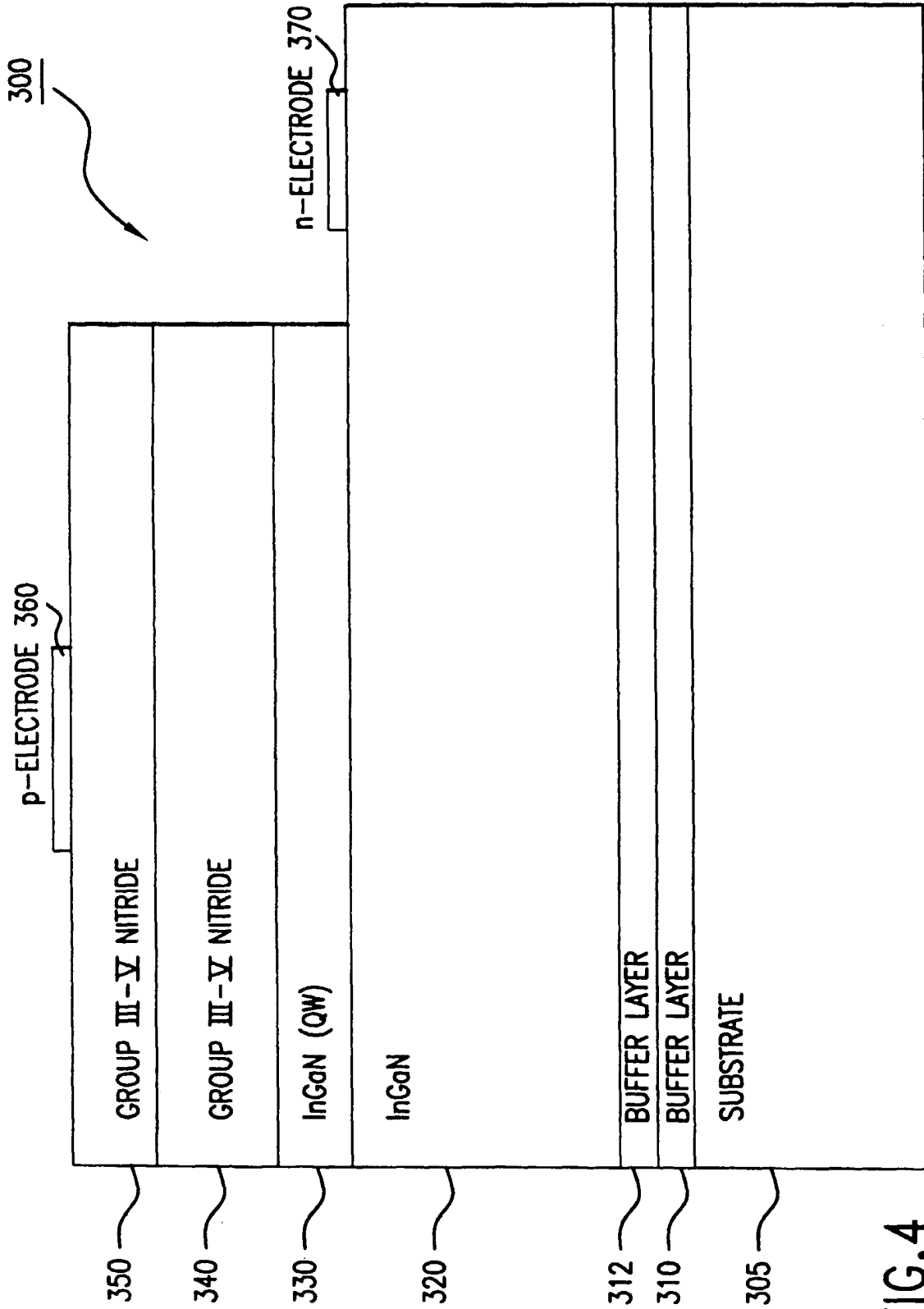


FIG.4

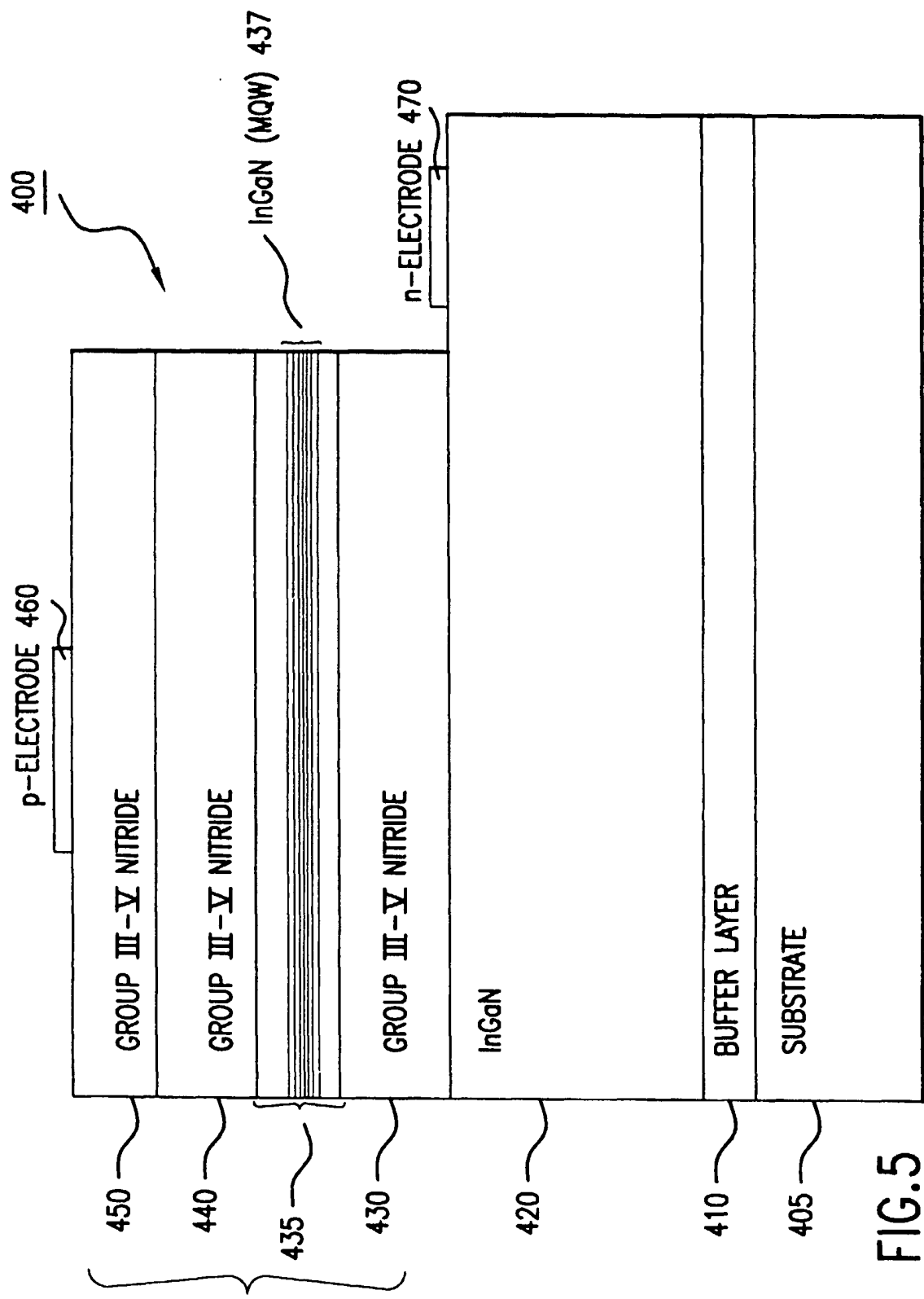


FIG.5

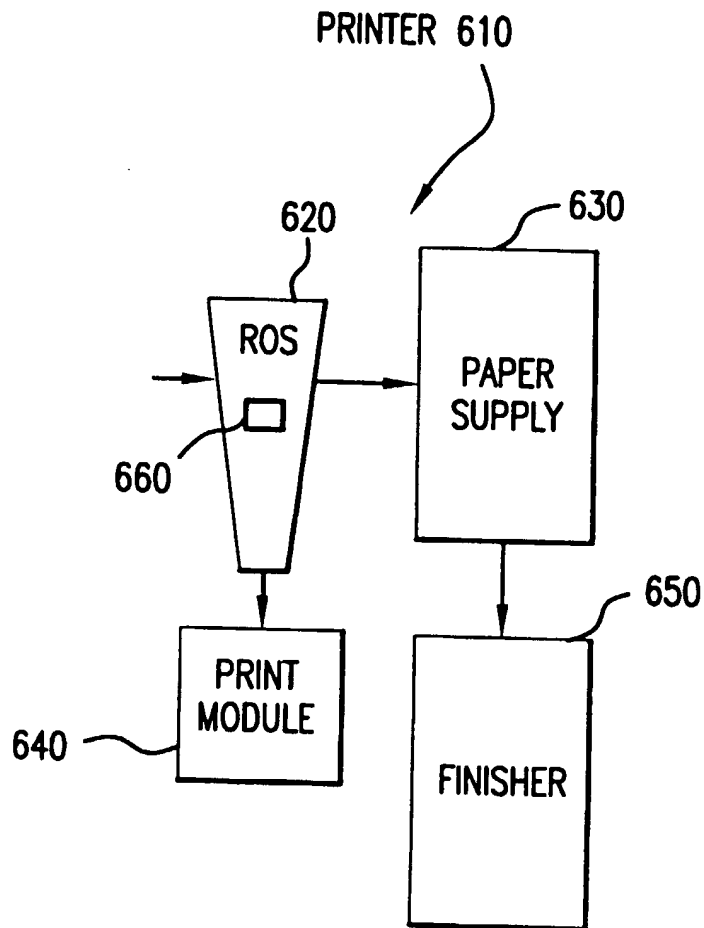


FIG.6

(19)



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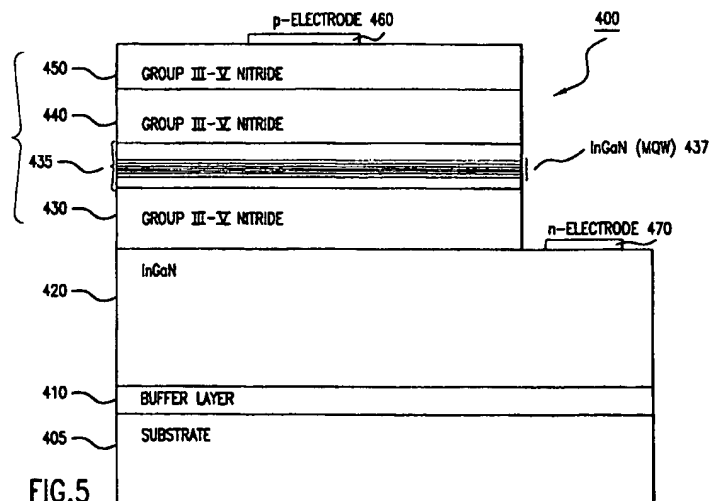
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**(54) AlGaInN LED and laser diode structures**

(57) Group III-V nitride semiconductors are used as optoelectronic light emitters. The semiconductor alloy InGaN is used as the active region in nitride laser diodes and LEDs, as its bandgap energy can be tuned by adjusting the alloy composition, to span the entire visible spectrum. InGaN layers of high-indium content, as required for blue or green emission are difficult to grow, however, because the poor lattice mismatch between GaN and InGaN causes alloy segregation. In this situation, the inhomogeneous alloy composition results in spectrally impure emission, and diminished optical gain. To suppress segregation, the high-indium-content In-

GaN active region may be deposited over a thick InGaN layer, substituted for the more typical GaN. First depositing a thick InGaN layer establishes a larger lattice parameter than that of GaN. Consequently, a high indium content heterostructure active region grown over the thick InGaN layer experiences significantly less lattice mismatch compared to GaN. Therefore, it is less likely to suffer structural degradation due to alloy segregation. Thus, the thick GaN structure enables the growth of a high indium content active region with improved structural and optoelectronic properties, leading to LEDs with spectrally pure emission, and lower threshold laser diodes.





European Patent  
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# EUROPEAN SEARCH REPORT

Application Number  
EP 99 30 5694

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			H01S H01L
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 6 November 2000	Examiner Hervé, D
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